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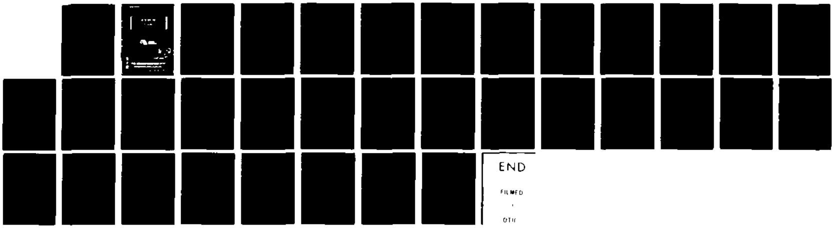

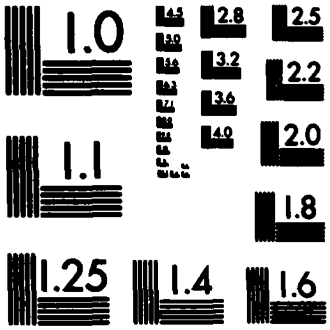

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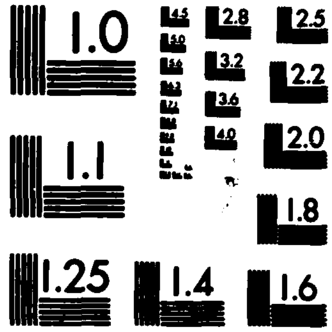

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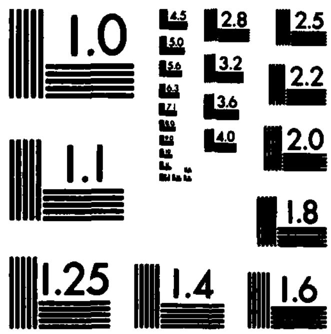

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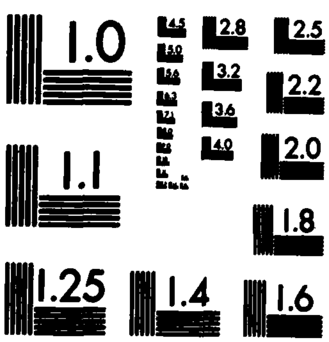

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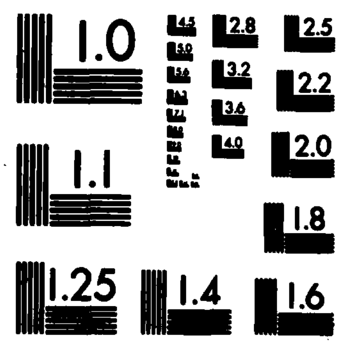

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Fourteen off-the-shelf navigation systems were considered for use in long-life, drifting buoys to provide localization information. Cost, power consumption, accuracy, capability for remote initilization, and packaging suitability for buoy use were used as criteria in the evaluation. Three U.S.-manufactured systems were selected in a two-stage preliminary review; two of

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these systems were purchased and tested in a laboratory and the other was evaluated on the basis of technical information supplied by the manufacturer. All three systems, the Magnavox MX-4102; the Navigation Communication Systems Meridian unit, and the Tracor Bridgestar, met or exceeded the criteria for long-life, drifting buoy use. An at-sea test is recommended as the next step in demonstrating their suitability.

REPORT #ATR-82-129-7A

LOW-COST NAVIGATION SYSTEMS FOR LONG-LIFE DRIFTING BUOYS

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EXECUTIVE SUMMARY

The Amron Corporation has completed an evaluation of 14 off-the-shelf, small boat navigation systems suitable for providing location accuracies of 1.1 km (0.6 nmi) on long-life (greater than 14 days), drifting buoys. Preliminary review eliminated 11 navigators either because of cost or high power consumption or because they are manufactured in foreign countries and not significantly better than similar U.S.-manufactured units. The three remaining units were

- the MX-4102, manufactured by Magnavox, Inc.;
- the Meridian, manufactured by Navigation Communication Systems, Inc.; and
- the Bridgestar, manufactured by Tracor Instruments.

Amron purchased two of these units and tested them in the laboratory; funding limitations prevented purchase of the third, but sufficient technical information was supplied by the manufacturer to complete the evaluation.

Five criteria were used in the evaluation: cost, power consumption, accuracy, capability for remote initialization, and packaging suitability for buoy use. The evaluation found that

- initial costs range from \$3000 to \$5000; some additional costs will be incurred for minor modifications;

- power consumption for continuous operation is 6.6 watts for the Meridian unit, and with minor modification, the MX-4102 and Bridgestar units can operate at about 9 watts; power consumption can be further reduced in all three units by operating them intermittently, with modification for intermittent operation easiest on the MX-4102;

- the two laboratory-tested units have position variances of less than ± 0.2 km (± 0.1 nmi) for their fixed locations; all three are expected to meet the accuracy criteria of ± 1.1 km (± 0.6 nmi) [with a maximum drift of 1.54 m/sec (3 knots)];

- all three units can be initialized remotely after minor modifications; and

- the Meridian unit is packaged such that it can be readily mounted in a buoy after removal of the front panel; the other two units require only minor additional modifications to be suitable for buoy mounting.

All three units were found suitable for use in long-life, drifting buoys. An at-sea test is now recommended as the next step in demonstrating their suitability.

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INTRODUCTION

Drifting, long-life (greater than 14 days) data buoys are becoming increasingly attractive for the collection of ocean data. The costs of using ships to collect such data are already prohibitive in most cases and are growing; and the cost for providing reliable moored buoy systems has always been high, particularly when the data are collected from the turbulent upper ocean layer [down to 200 m (656 ft)].

An advantage in using drifting, long-life data buoys is that they can be quickly emplaced by the military at distant ocean locations. Furthermore, low-cost, low-power electronic and microcomputer systems and improved energy storage technology have greatly increased their cost-effectiveness.

To be cost effective, the drifting buoy must incorporate a low-cost, low-power navigation system. The five navigation system candidates considered for use in drifting buoys were the TRANSIT navigation satellite system, the Global Positioning System (GPS), LORAN-C, the ARGOS satellite system, and OMEGA. Of these, the low-cost TRANSIT system currently available for small boats best fulfills the current navigation requirements for worldwide use on U.S. Navy drifting buoys, and it is discussed in detail in this report. The other four systems are discussed briefly in the following paragraphs.

The GPS system, currently under development by the Department of Defense, is a satellite-based navigation system that will eventually replace the current TRANSIT system. Since the GPS navigation system continuously receives data from four satellites, it can determine three coordinate positions and velocities to very high accuracies. However, because the GPS is a four-channel system, its current costs are high. Cost projections for an austere, single-channel system are between $2500 and $6000, but such systems are not expected to be available before 1990.*

LORAN-C is a low-frequency (approximately 100 kHz) radio navigation system using land-based transmitters. The cost of the LORAN-C receiving system is low, the power requirements are low, and the system offers high accuracy near the transmitting sites. However, LORAN-C accuracy gradually deteriorates with increasing distance from the transmitters. The daytime range is about 2000 km (1250 mi) and extends to about 3200 km (2000 mi) at night. The LORAN-C system coverage is inadequate since drifting buoys must be capable of operation in any of the ice-free seas and oceans of the world. LORAN-C coverage, for example, does not exist in large areas of strategic importance such as the Indian Ocean or South Atlantic Ocean. LORAN-C does, however, give superior performance in the waters off the U.S. coasts and those off many parts of the European coast.

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* "NAVSTAR: the All-Purpose Satellite," Robert P. Denaro, IEEE Spectrum, May 1981, IEEE Press, New York, NY.

The ARGOS system is an international data collection and platform location system maintained by the French. The platform localization scheme is satellite navigation in reverse; that is, the drifting buoy has a precision transmitter, and a doppler signal is measured by a land-based receive site as the satellite passes over the buoy. ARGOS has the advantage of requiring low-cost, low-power buoy electronics and can provide position accuracies to better than ±2 km (±1.25 nmi). However, because ARGOS involves participation of a foreign government, it is probab'.y not suitable for most U.S. Navy applications.

OMEGA is a very low frequency (VLF) (10 kHz to 14 kHz) navigation system that provides a new position fix every 60 seconds. Like satellite navigation, it is a truly global system, offering ±2 to ±3 km (±1.25 to 7.75 nmi) accuracy. Its disadvantages are that the receiver system must operate continuously to maintain lane counts and its accuracy can be significantly degraded by local thunderstorm activity.

SYSTEM AVAILABILITY AND SELECTION

This study identified 14 currently available small boat navigation systems that operate with the TRANSIT satellite. Some characteristics of these systems are shown in Table 1.

An initial review of the 14 units resulted in elimination of

- the ESZ-3900, TSN-1, and RAYSAT-100 because of high power consumption and
- the Horizon 209, FSN-70, and NQ-909 because of high price.

Although some of the units that were elimated had desirable features for small boat operations (for example, video displays), none offered features significantly better for buoy application than the lower-cost, lower-power units remaining in consideration. A seventh unit, the Transtar, was eliminated because it offered no technical features for buoy use over the Bridgestar unit. (If there were a specific requirement to mate a TRANSIT system with an OMEGA system, a Transtar unit should be considered as a starting point.)

The remaining seven units, with varying levels of modification, were judged to be suitable candidates for drifting buoy application. Three of these units are manufactured in the United States. The only foreign-manufactured unit that offers a significant feature not available on U.S.-manufactured units is

TABLE 1. POWER, COST, AND PLACE OF MANUFACTURE FOR SMALL BOAT SATELLITE NAVIGATION SYSTEM

MANUFACTURER AND MODEL	POWER (watts)	COST ($)	PLACE OF MANUFACTURE
Brookes and Gatehouse, Inc.			
• Horizon 209	14	$6,995	England
Furuno USA, Inc.			
• FSN-70	NA	6,995	Japan
International Marine Instruments, Inc.			
• Combi 502	8	2,990	England
• Combi 902	8	4,995	England
Magnavox Advanced Products & Systems Co.			
• MX 4102	8-15	2,995	USA
Navidyne, Corporation			
• ESZ-3900	65	6,950	USA
Navigation Communication Systems, Inc.			
• Meridian	6	3,995-5,995	USA
Racal-Decca Marine, Inc.			
• Sat-Nav 402	14-18	2,995	England
Radar Devices, Inc.			
• TSN-1	25	4,850	USA
Rauff and Sorensen A/S			
• Okeanos Shipmate RS-5000	12	2,850	Denmark
Raytheon Marine Co.			
• RAYSAT-100	38	4,995	Japan
Simrad			
• NQ-909	NA	5,995	Norway
Tracor Instruments			
• Bridgestar	14	2,950	USA
• Transtar	14	4,850	USA

the Combi 902. It has a sleep feature that allows the major power-consuming components to be turned off to conserve power between satellite passes. A similar capability, however, can be incorporated into the Magnavox MX 4102 unit with only minor modifications because of the MX4102's "keep-alive" memory feature. With more extensive modification, this feature can also be incorporated into the Meridian and Bridgestar units.

As a result of the second review, the four foreign-manufactured units were eliminated, and only the three U.S.-manufactured units were studied further. Two of the three selected units (the MX-4102 and the Meridian units) were purchased and tested at Amron. Project funding limitations prevented purchase of the Bridgestar unit, but its manufacturer, Tracor Instruments, provided extensive technical information on its performance.

POWER MEASUREMENT RESULTS

The three TRANSIT (NAVSAT) systems selected for detailed analysis (MX-4102, Meridian, and Bridgestar units) meet most of the performance requirements for a buoy navigator. For example, with a 0.5-m/sec (1-kt) drift, each unit should be able to maintain a location accuracy of ± 0.4 km (0.2 nmi), which is sufficient for most anticipated buoy applications; the antenna environment is similar to that of a small boat, etc. In the economic areas, specifically the cost of battery power, significant improvement is needed if TRANSIT systems are to gain wide acceptance in drifting buoys. Rough estimates of power cost* for three types of batteries are:

• lead-acid:	$100/kilowatt-hour
• lithium/thionyl-chloride:	$400-600/kilowatt-hour
• silver zinc:	$1000/kilowatt-hour

Thus, the battery power cost of a 10-watt system using a lead-acid battery would be $24/day; battery power cost for a similar 5-watt system would be $12/day. (For reference, the ARGOS system charges $15/day per platform to supply platform location data.) Power measurements were undertaken to attempt to determine how power savings might be achieved.

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*The cost for the additional buoyancy necessitated by the weight of the batteries has not been calculated in this study. It could, however, increase the system costs considerably.

MAGNAVOX MX-4102 UNIT

The MX-4102 unit is one of the most recent TRANSIT navigator systems and is the system that established the downward cost during the early part of 1982. Figure 1 shows the power consumption of the MX-4102 unit as a function of input voltage with and without a display panel*. A significant 4.5-watt power savings can be realized by removing the display panel.

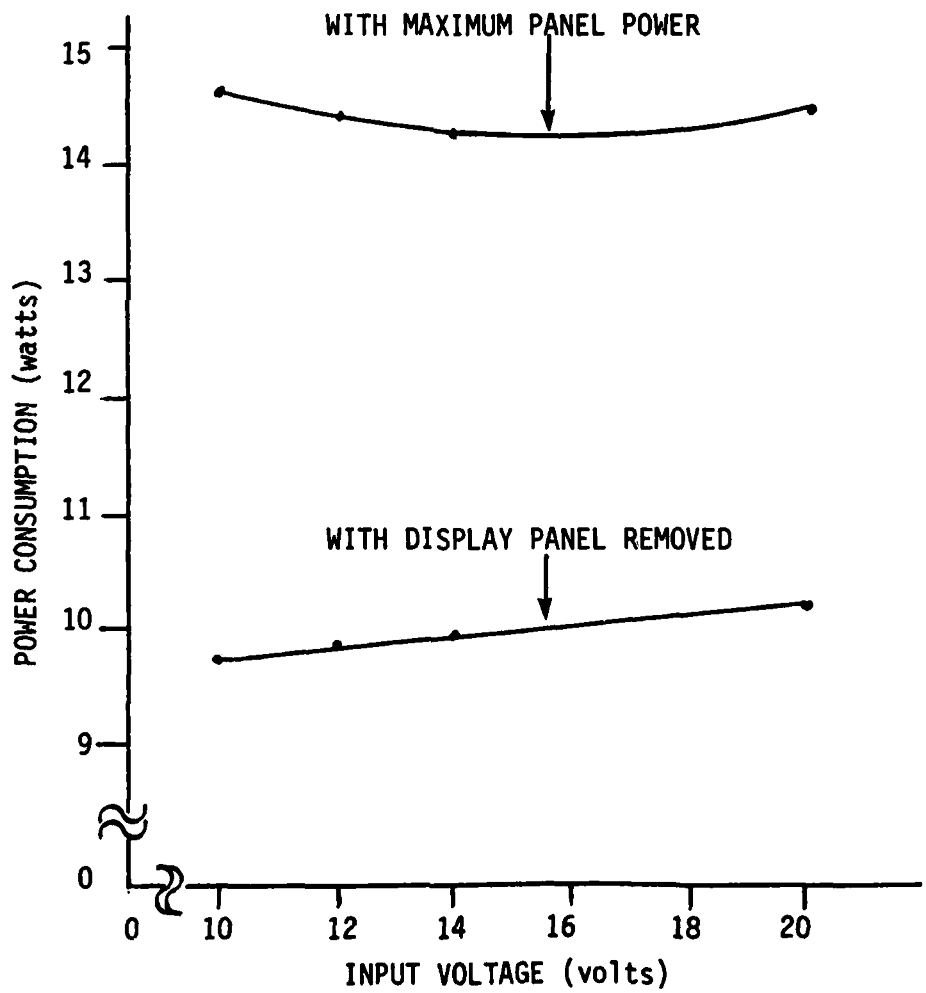

FIGURE 1. MX-4102 POWER CONSUMPTION AS A FUNCTION OF INPUT VOLTAGE WITH AND WITHOUT DISPLAY PANEL

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*Appendix A presents the measurement methodology used.

Figures 2 and 3, respectively, show the partitioned power breakdown for the MX-4102 unit with and without the display panel connected. The MX-4102 power supply delivers three voltages (nominally +5, +12, and +60 volts). In the figures, the frequency reference power is shown at its stabilized value for a laboratory temperature of 21 degrees Celsius (approximately 70 degrees Fahrenheit). From a cold start, the frequency reference consumes 3.92 watts and remains at that value for about 10 minutes. It takes about 30 minutes for the frequency reference to stabilize to the 1.69-watt power value shown in Figures 2 and 3. If heat is applied to the frequency reference, its power consumption drops; it returns to its nominal power level in a short period of time when heat is removed.

NAVIGATION COMMUNICATION SYSTEMS (NCS) MERIDIAN UNIT

The NCS Meridian unit is available in both standard commercial and military versions. The military version was evaluated in this study because it has undergone complete environmental testing and it has military connectors and mountings that would facilitate its placement in a buoy.

The power consumption of the Meridian unit is shown in Figure 4 as a function of input voltage with and without display panel illumination, and the partitioned power is shown in Figures 5 and 6. The power supply delivers three voltages (nominally -5, +5, and +12 volts). The frequency reference power could not be

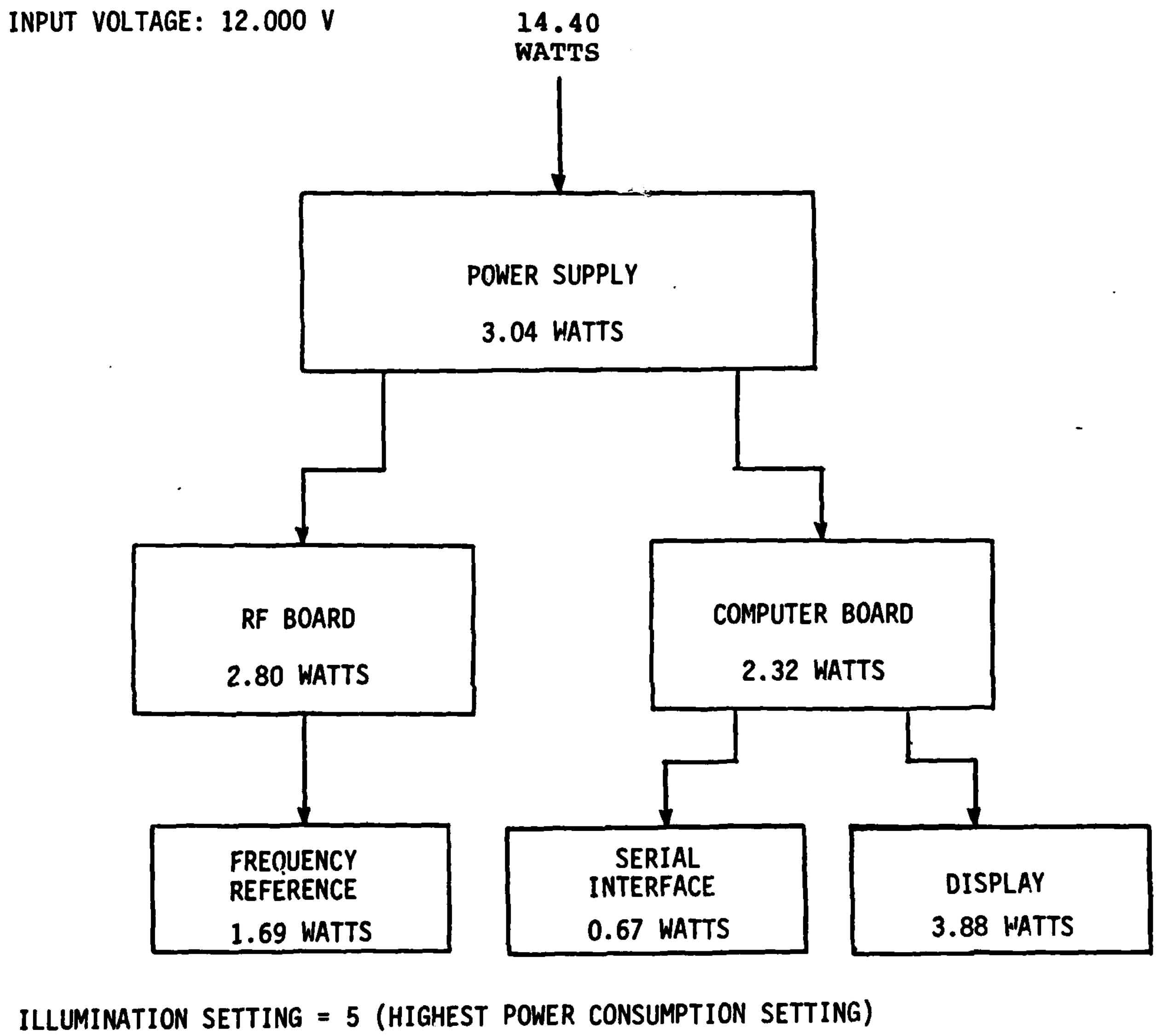

FIGURE 2. POWER PARTITIONING FOR THE MAGNAVOX MX-4102 WITH DISPLAY ON.

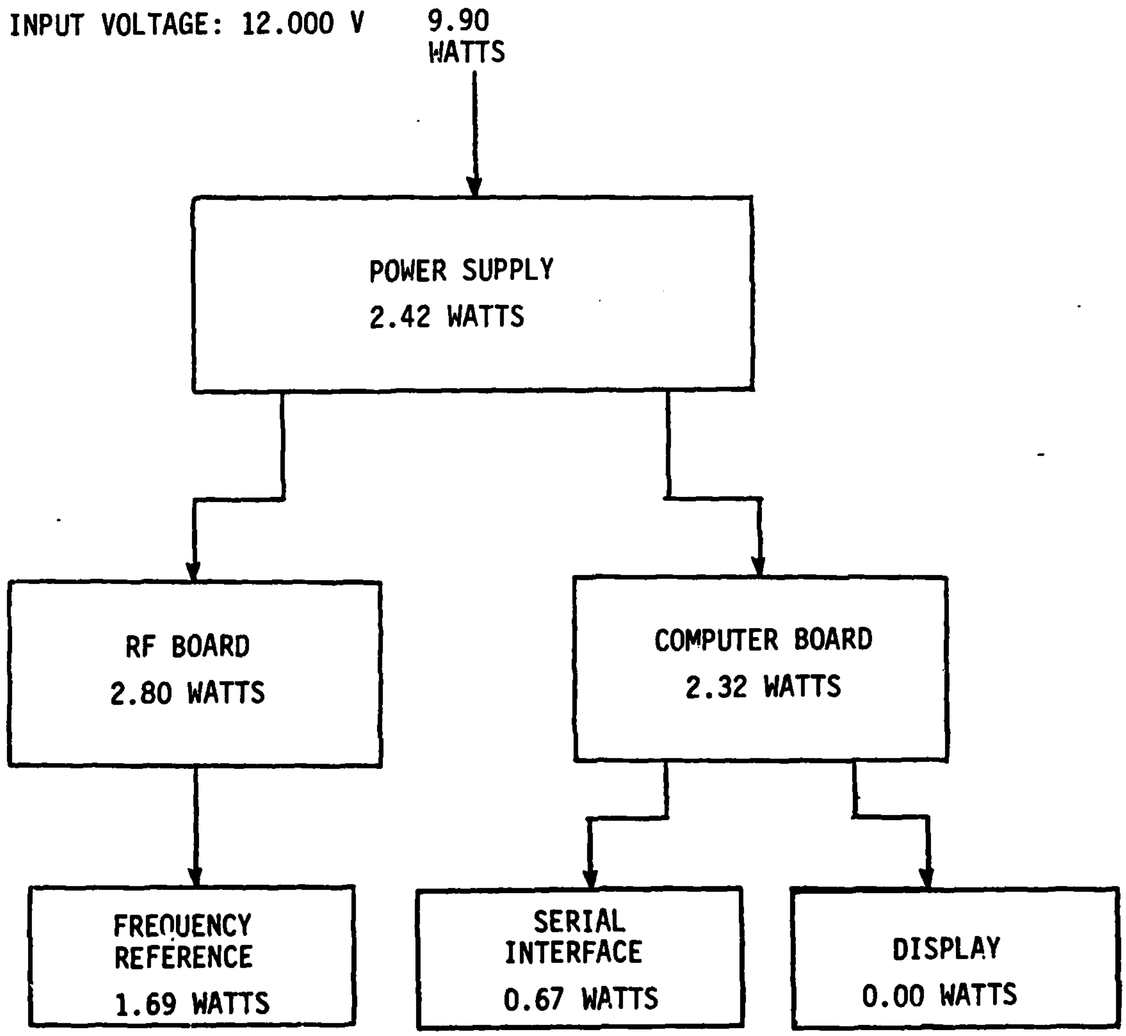

FIGURE 3. POWER PARTITIONING FOR THE MAGNAVOX MX-4102 WITH THE DISPLAY PANEL DISCONNECTED.

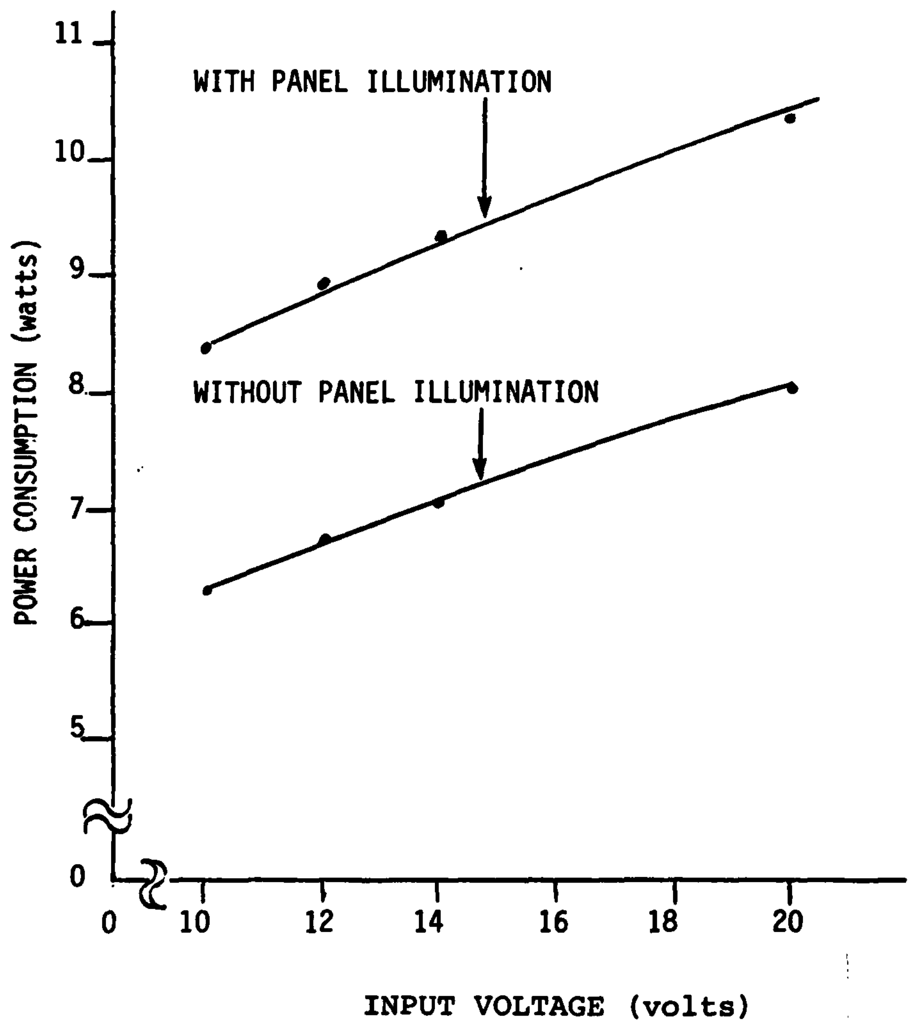

FIGURE 4. MERIDIAN UNIT POWER CONSUMPTION AS A FUNCTION OF INPUT VOLTAGE WITH AND WITHOUT PANEL ILLUMINATION.

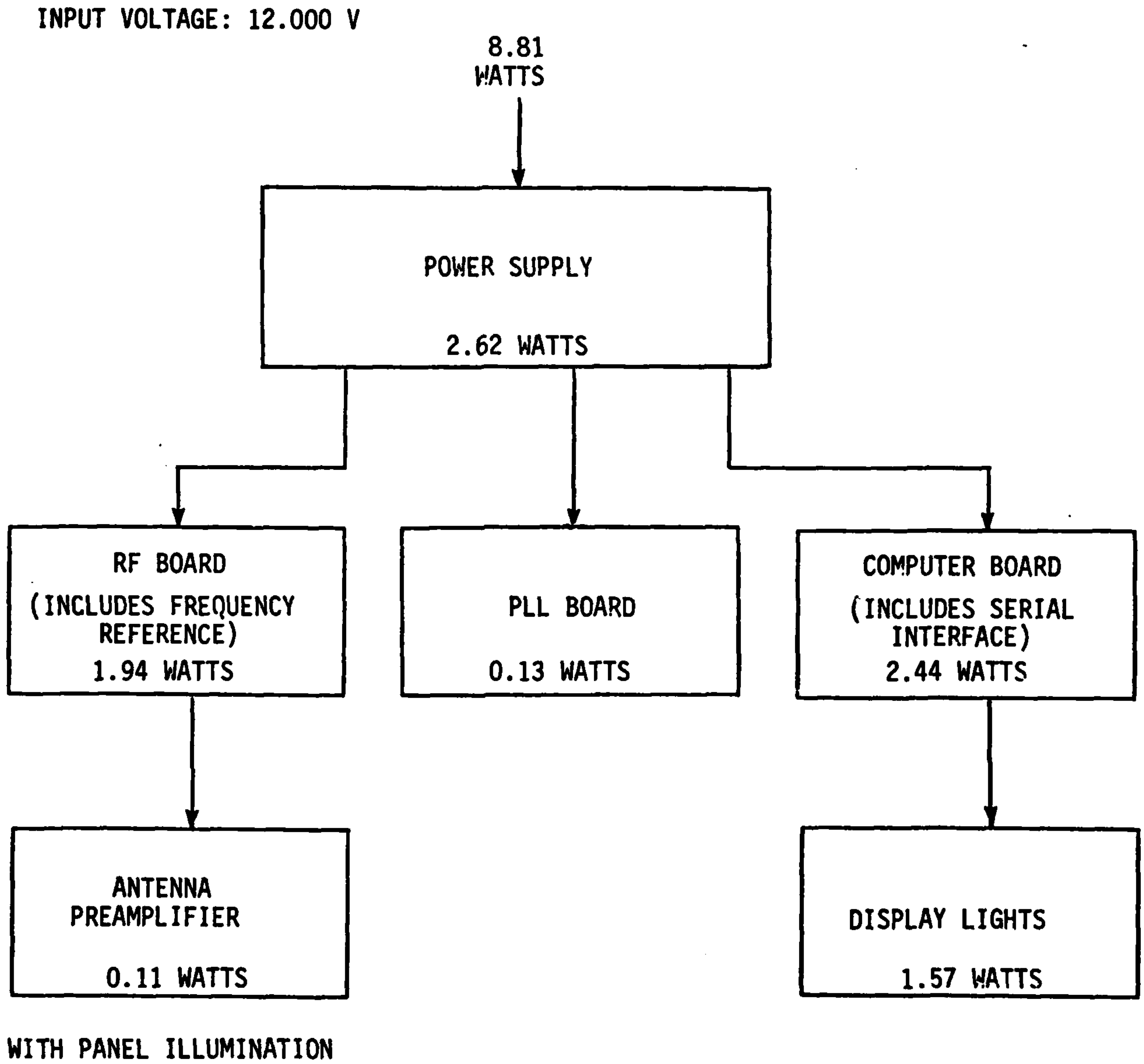

FIGURE 5. MERIDIAN UNIT POWER PARTITIONING WITH PANEL ILLUMINATION.

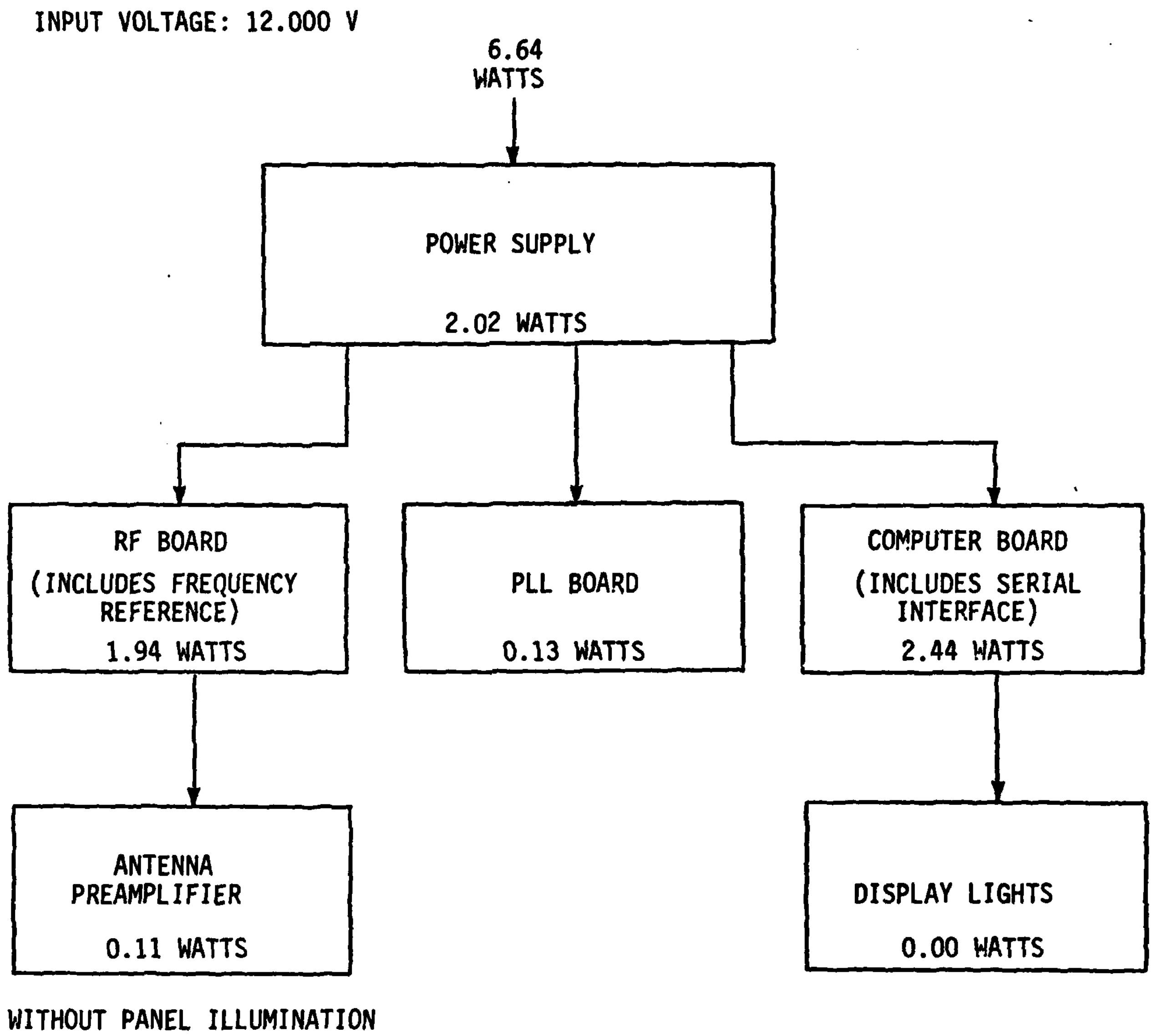

FIGURE 6. MERIDIAN UNIT POWER PARTITIONING WITHOUT PANEL ILLUMINATION.

The power consumption of the Meridian unit is shown in Figure 4 as a function of input voltage with and without display panel illumination, and the partitioned power is shown in Figures 5 and 6. The power supply delivers three voltages (nominally -5, +5, and +12 volts). The frequency reference power could not be measured without damaging the RF printed circuit board, but the power for it is included in RF board power. Table 2 presents the change that occurs in the RF circuit board +5 volt power supply power from a cold start.

NCS has apparently devoted considerable effort to lowering the power consumption of its unit. To do so, it has used liquid crystal displays (LCDs) and a low-power frequency standard and has effected power reductions on RF and computer circuit boards.

TABLE 2. MERIDIAN RF BOARD POWER FROM A COLD START

CONDITION*	RF BOARD +5-VOLT SUPPLY (watts)	TOTAL NAVIGATOR (watts)
COLD START	2.264	8.52
30-MINUTES LATER	0.987	6.54

*Antenna Preamplifier not connected.

TRACOR INSTRUMENTS BRIDGESTAR UNIT

The normal unmodified Bridgestar navigator consumes 14 watts, but Tracor anticipates that this consumption can be reduced to 8.5 watts by removing the front panel and making other minor changes. The Bridgestar unit is capable of unattached operation and has built-in self-test features. Like the MX-4102 and Meridian units, the Bridgestar has a serial data port (20 ma current loop) that can interface with telemetry. Tracor indicates that with only minor software/firmware changes, this port can be made bidirectional, which would allow remote initialization and control of the system after removal of the front panel. The power supply circuits use the nominal 12-volt (10- to 15-volt) primary power source to produce voltages of +9, -8, and -5 volts. Tracor has very good quality operation and service manuals available for the Bridgestar system.

INTERFACE TO TELEMETRY

The level of complexity of the interface between the satellite navigator unit (SNU)* and the data telemetry unit (DTU) is greatly dependent on the degree to which the two units have been specially designed to operate with one another. It is possible to use independently designed and largely unmodified SNUs and DTUs if a navigator interface unit (NIU) is installed between them as shown in Figure 7. The SNU outputs its data in the format it would normally use as output to a printer. The NIU then selects the data that are to be transmitted and converts that data to a telemetry format. Any control required by the SNU will be provided by the NIU. Requests for printer output, power down, and reinitialization are examples of control functions that the NIU might provide to the SNU. The NIU also passes data to the DTU and handles any "handshaking" control functions with the DTU.

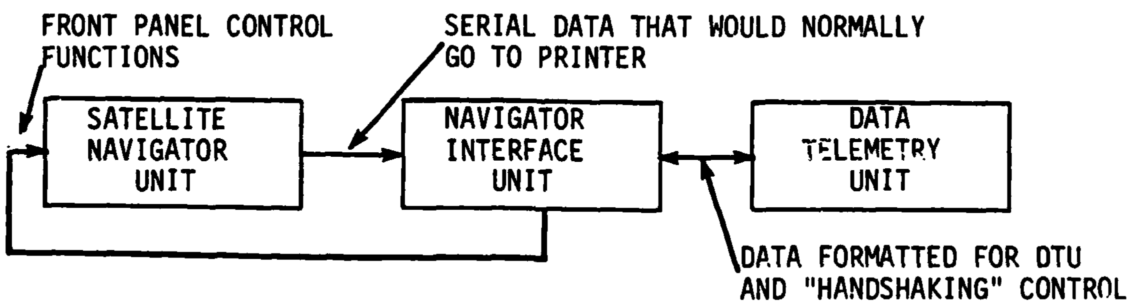

FIGURE 7. SATELLITE NAVIGATOR TO DATA TELEMETRY INTERFACE (VERSION 1)

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*A more correct title for the SNU would be a navigation system

The SNU normally receives control inputs from its front panel; If the SNU can be modified to accept those inputs through the serial data port, the hardware in the NIU could be simplified to that shown in Figure 8.

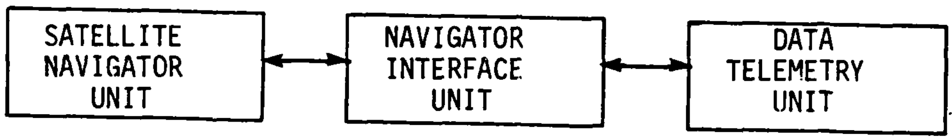

FIGURE 8. SATELLITE NAVIGATOR TO DATA TELEMETRY INTERFACE (VERSION 2)

Finally, if a "smart" DTU is used in combination with a modified SNU, the interface can be further simplified to that shown in Figure 9. In this case, all of the NIU functions are performed in either the SNU or the DTU.

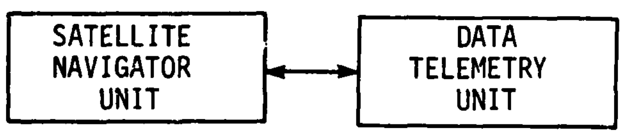

FIGURE 9. SATELLITE NAVIGATOR TO DATA TELEMETRY INTERFACE (VERSION 3)

As an interim measure, it is possible to build an NIU similar to that shown in Figures 7 and 8 so that off-the-shelf SNUs and DTUs units can be used in a buoy demonstration. Amron estimates that such an NIU could be constructed from commercially available RCA COSMAC microboard's and would consume well below

one watt of power*. The RCA COSMAC system uses an RCA 1802. microprocessor and has a large variety of 11.4 cm (4.5 in.) X 19.1 cm (7.5 in.) boards available to construct a complete microcomputer system. With three to eight of these boards, it would be possible to construct an NIU that would greatly minimize the need for any new or specialized hardware fabrication.

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*Actual estimate is about 250 mW.

CONCLUSIONS

The original program objective as stated in the Amron proposal of August 1981 was to obtain a buoy navigation system with the following features:

- a unit production cost of $5,000 to $10,000;
- an average power consumption of 5 to 10 watts;
- an accuracy of ±1.1 km (±0.6 nmi) [with a maximum drift velocity of 1.54 m/sec (3 knots)];
- the capability of being initialized by remote equipment; and
- packaging suitable for buoy applications.

All of these features were met or exceeded by the three navigation systems selected for detailed analysis.

COST

The original concept stated in the Amron proposal was to keep costs down by using an off-the-shelf, commercially available navigation unit and modifying it as necessary for the buoy application. Because of the significant navigator cost reductions that occurred in marketplace in 1982, costs near $5000 should be attainable. For example, the MX-4102 and Bridgestar units are avialable for less than $3000 in small quantities. An additional cost of about $2000 to $3000 per unit is estimated for minor modifications to the satellite navigation unit (SNU) and hardware costs for the navigation interface unit (NIU). Some one-time software development costs for the NIU will be incurred.

If quantities of the order of 100 to 1000 units are required, modified production SNUs compatible with a smart telemetry system (one without an NIU) could probably be obtained for about $2000 to $3000.

POWER CONSUMPTION

The original power consumption objective of 5 to 10 watts can be achieved with only minor modifications to the MX-4102, Meridian, or Bridgestar units. For example, the MX-4102 unit could operate continuously at 9.9 watts with only the display functions deleted. If an NIU of about 0.5 watt is assumed, the daily power consumption for the combination would be 250 watt-hours, which would translate to a battery (lead-acid) cost of $25 per day. The original power consumption objective is probably too high for many of the new small drifting buoy concepts, because of battery weight. Significantly lower average power consumptions would be desirable for these systems. If only four fixes per day were desired*, the MX-4102 unit could be turned off most of the time.**

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*On the average, with five TRANSIT satellites in orbit, the number of available good satelitte passes (those in which the satellite elevation angle is between 8 degrees and 70 degrees) will vary from about 15 at the equator to 45 at 70 degrees latitude.

**All of the satellite navigation systems provide extremely accurate 24-hour advance notice of their future passes.

The following power-on conditions would exist:

- the NIU would operate continuously at an estimated 0.5 watt;

- the frequency reference oven would be turned on through a special power supply 30 minutes before an expected satellite pass (5 watts estimated for power supply plus frequency reference oven); and

- the entire SNU would be turned on 5 minutes before an expected pass and left on for 20 minutes.

This power-on condition would result in a combined daily power consumption for the SNU and NIU of about 35 watt-hours*, which would translate to a battery (lead-acid) cost of $3.50 per day.

The Meridian unit could operate continuously at 6.64 watts with no modifications. Continuous operation of an NIU at an estimated 0.5 watts would yield a daily power requirement of 170 watt-hours, which would translate to a battery cost of $17.00 per day. Unlike the MX-4102, the standard Meridian unit does not

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*POWER REQUIREMENT= (0.5 x 24) + (4 x 5 x 1/2) + (4 X 9.9 X 1/3)
=35 WATT-HOURS/DAY

have a memory "keep-alive" function, a feature that greatly facilitates modification for intermittent operation. Assuming that such a function could be provided, it would probably be possible to build a four-fix version of the Meridian unit with an NIU that would require less than 30 watt-hours, which would mean a battery cost of less than $3.00 per day.

For continuous operation, the Bridgestar power consumption is close to that of the MX-4102. Even though it does not have the memory keep-alive feature, it appears that Bridgestar could be modified for intermittent operation.

If a 250 mW (average power) NIU could be build and other power-saving modifications could be made to the SNU, an estimated additional 8 to 10 watt-hours per day could be saved from the above energy estimates for a four-fix system.

ACCURACY

In a laboratory environment, the MX-4102 and Meridian units had a position variance for their fixed location of under ±0.2 km (±0.1 nmi). There is every reason to expect that the MX-4102, Meridian, or Bridgestar could achieve accuracies of ±1.1 km (±0.6 nmi) with a maximum drift velocity of 1.54 m/sec (3 knots). Since most drift currents are expected to be under 0.5 m/sec (1 knot), a normal location accuracy of better than ±0.35 km (±0.2 nmi) is estimated.

SYSTEM INITIALIZATION

The MX-4102, Meridian, and Bridgestar units can all be initialized by remote equipment with a minimum of modification.

PACKAGING

The military version of the Meridian unit comes packaged so that it can be mounted in a buoy and require only the replacement of the front panel. The enclosure is sealed (water resistant) and has military type connectors. The MX-4102 and Bridgestar units would each require only a modest amount of modification (replacing the front panel, adding military type connectors, modifying mountings, and adding some case sealing).

RECOMMENDATIONS

The MX-4102, Meridian, and Bridgestar navigator units have been assessed as suitable for buoy applications. The most important remaining task is to demonstrate their suitability in an at-sea buoy test. Such a test would probably best be conducted by deploying the buoy/navigator in U.S. coastal waters at a site at which the position accuracy of LORAN-C is high. Thus, LORAN-C position fixes and those of the TRANSIT satellite could be compared. To minimize costs, it is recommended that an off-the-shelf telemetry system be used, possibly operating through the Geostationary Operational Environmental Satellite (GOES) system or a high-frequency link to a ground station.

APPENDIX A

MEASUREMENT PROCEDURE

All current measurements in this study were taken by using a Hewlett-Packard Model 428B clip-on DC milliammeter. A Beckman HD 100 3-1/2-digit digital multimeter was added to the analog output of the clip-on milliammeter to facilitate readings. All voltages were measured with a Fluke 8060A 4 1/2-digit digital multimeter. The DC milliammeter was calibrated with a known current before each set of runs to verify its accuracy.

The Magnavox MX 4102 satellite navigator consists of five printed circuit boards (power supply, computer, RF, display, and serial interface) interconnected by ribbon cables. The currents between the power supply and other boards were measured by separating the wires in the ribbon cables and attaching the clip-on meter. A short special cable was fabricated to measure the frequency standard power.

The Navigation Communication Systems, Inc., Meridian unit consists of three printed circuit boards (RF, phase lock loop, and computer) that plug into a power supply "mother board." The display is connected by a cable. A special extender board was fabricated to measure the currents from the power supply mother board to individual boards.

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